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AUTOMATED AND CONVENTIONAL PHOTOMETRY OF THE SHORT-PERIOD VARIABLE STAR 14 AURIGAE*

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ABSTRACT

Amplitude of the V-light curve of the δ Scuti star 14 Aurigae varied from 0.02 to 0.08 mag on six nights. The changes in amplitude accompanied comparable changes in maximum brightness, whereas changes in minimum brightness were much smaller. The light period is $0^{d}08748$, and the spectroscopic-binary period is $3^{d}788506$. Small variations in color indices, associated with the light variation, resemble those of other δ Scuti stars. The use of an automated telescope was effective in obtaining large numbers of routine observations.

I. INTRODUCTION

Harper (1916, 1938) discussed 14 Aurigae (HR 1706, spectral type A9 V, $\alpha = 05^{h}12^{m}10^{s}$, $\delta = +32°38'$ [1950]) as a spectroscopic binary of period $3^{d}78873$. Danziger and Dickens (1967) showed that it is a short-period-variable star, probably of the δ Scuti type, and estimated the light period at about $0^{d}122$. Chevalier, Perrin, and Le Contel (1968) obtained simultaneous photometric and spectroscopic observations and derived a light period of about $0^{d}0938$. They suggested that the pulsation may be nonradial, possibly with the pulsation axis directed along the line that joins the centers of the two components of the binary. The present work was undertaken to extend our knowledge of the photometric behavior of 14 Aurigae and to evaluate the effectiveness of an automatic system for routine observations such as variable-star monitoring.

II. EQUIPMENT AND OBSERVATIONAL PROCEDURES

We used a remotely controlled, 50-inch automated telescope[1] (Maran 1967) at the Kitt Peak National Observatory. The telescope was equipped with a three-channel photoelectric photometer for simultaneous UBV measurements (Maran 1969). In addition, the No. 4 16-inch telescope at Kitt Peak was operated manually on two occasions, with a single-channel photometer and a V-filter, to obtain additional data on the variable star and to provide a conventional standard of comparison for data obtained with the automated system. Charge integrators were used with both photometers.

In the observations made with both telescopes, χ Aur was used as the comparison star, following Danziger and Dickens (1967) and Chevalier *et al.* (1968); it was observed three times per hour by the automated telescope. As a further check, occasional observations were made of 18 Aur. Measurements of UBV standard stars were taken with the 50-inch telescope on one night (1969 January 8), and the extinction and transformation coefficients determined from these observations were applied to all of the data obtained with this telescope. The V-magnitudes obtained with the 16-inch telescope were reduced

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[1] The primary mirror was masked down to aperture 38 inches.

by adopting mean extinction coefficients kindly supplied by J. C. Golson (private communication).

The observing program for the 50-inch telescope was provided as a punched paper tape on the system computer, Raytheon model 250, located in Tucson. On each night, after initiating the program, the operator left the computer unattended, except for status checks at roughly 2-hour intervals. Details of the programming, telemetry, and command structure have been discussed elsewhere (Vokac and Stuart 1969). The output of the automated telescope was also on punched paper tape, in a format compatible with the larger computer (Control Data Corporation model 3600) that was used for the data analysis. Therefore, it was convenient to reduce individually the observations that were obtained with this instrument. The measurements on the 16-inch telescope were recorded as digital voltmeter readings of the integrator output. In the case of these data, individual sets of three consecutive measurements of a star were averaged before being reduced.

III. OBSERVATIONS

Observations were taken on eight nights during 1969 January. The automated telescope was operated even when the sky conditions were not photometric, in case useful intervals of good seeing might occur. For this reason, the observations sometimes continued as the star passed to fairly large air masses. The journal of observations is given in Table 1. The air-mass range in column (4) is presented in the format E-1-W, where E is the air mass of 14 Aur at the first observation before transit and W is the air mass at the last observation after transit. The "night rating" in the last column is based on the reproducibility of measurements taken in rapid succession, and also on estimates of the seeing for individual observations. The latter quantity is derived from the variations in the integration rate during a measurement. Data classed as "bad" are not included in the results.

The V-light curves obtained by the automated telescope on the two best nights, January 7 and 8, are shown in the upper portions of Figures 1 and 2, respectively. The ordinates are magnitude differences Δm, expressed in the sense "variable minus comparison"; the abscissae are geocentric Julian dates minus 2440220. In each case, the V data for χ Aur are given in the lower portion of the figure, and it is clear that the variation due to extinction has not been completely eliminated. Since 14 Aur and χ Aur are close together (their maximum separation in air mass was 0.1 during these observations) and the period of 14 Aur is so short, the lack of a complete extinction correction should not affect the results. This conclusion is supported by Figure 3, where the V-magnitudes of 14 Aur that were obtained on January 8 with the 16-inch telescope are shown as large

TABLE 1

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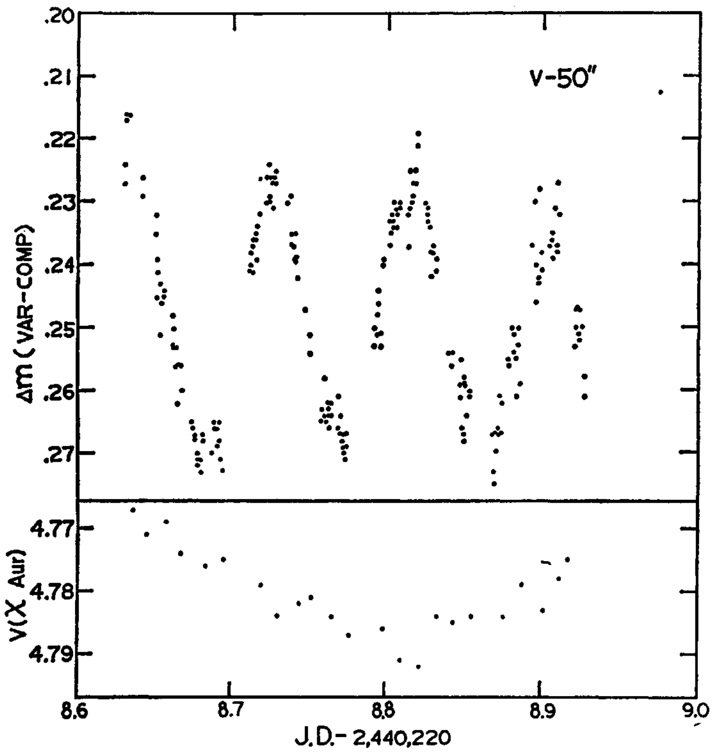
UT Date (1969) (1)	Telescope (inches) (2)	Range in Julian Date (less 2440220) (3)	Air-Mass Range (E-1-W) (4)	Night Rating (5)
January 5	50	6.60– 6.95	1.3–1–2.2	Bad at start; fair at end
January 7	50	8.63– 8.93	1.2–1–1.9	Good
January 8	16	9.58– 9.91	1.4–1–1.8	Good
January 8	50	9.62– 9.95	1.2–1–2.5	Good
January 9	16	10.68–10.83	1.4–1–1.2	Fair
January 18	50	19.76–19.92	1–2.4	Fair
January 20	50	21.60–21.86	1.1–1–1.5	Bad
January 21	50	22.62–22.87	1.1–1–1.7	Good at start; bad at end
January 23	50	24.61–24.72	1.1–1–1.0	Bad



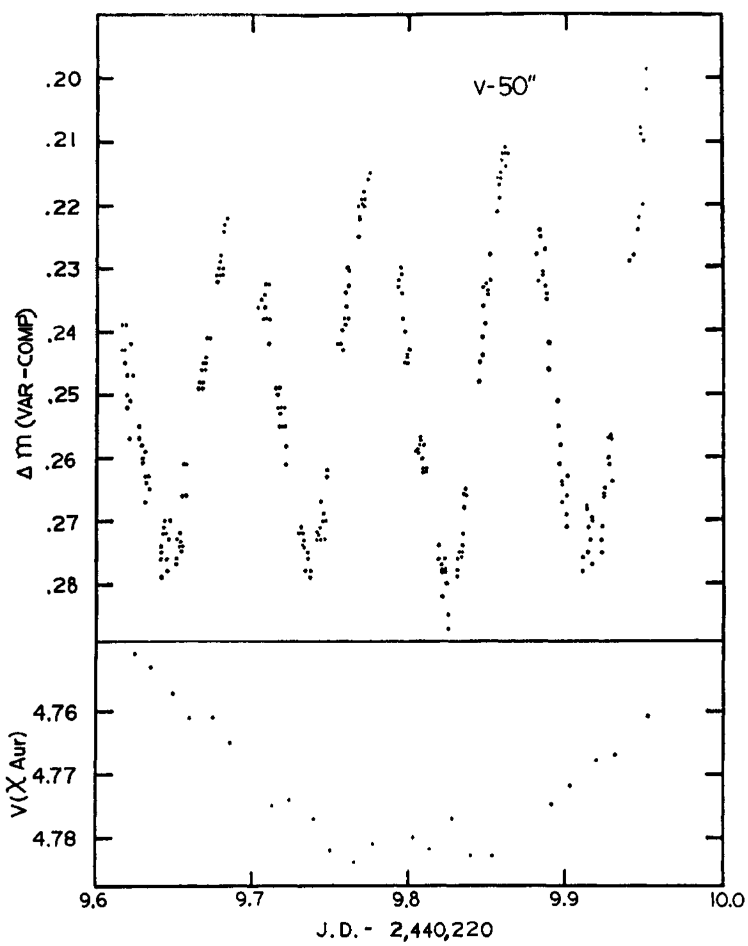


FIG. 1 (*top*).—*V*-light curve of 14 Aur for 1969 January 7, obtained with the 50-inch automated telescope. *Abscissae,* Julian Days minus 2440220; *ordinates,* magnitude differences in the sense "variable minus comparison." Some points are slightly displaced in the horizontal direction, to avoid overlap in plotting.

FIG. 2 (*bottom*).—*V*-measurements of χ Aur, same as Fig. 1, for 1969 January 8

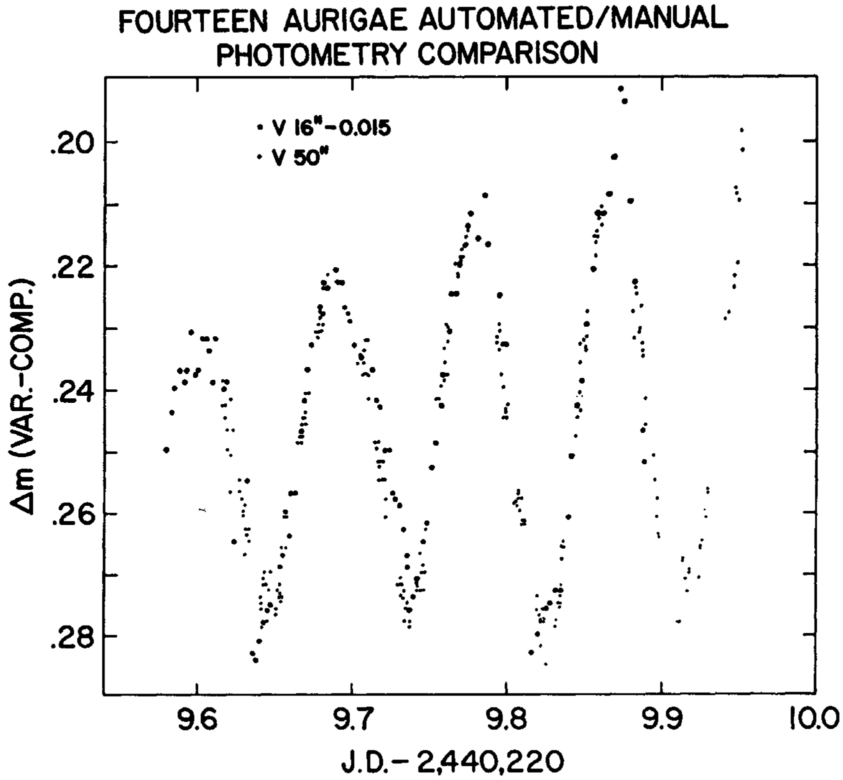


FIG. 3.—Improved V-light curve for 1969 January 8, prepared by adding measurements obtained with the No. 4 16-inch telescope (*large dots*) to the data of Fig. 2. A night correction of -0.015 mag has been applied to each 16-inch telescope measurement.

dots, along with the data of Figure 2. A 0.015-mag correction was subtracted from each 16-inch telescope measurement to reconcile the data of both telescopes. Since the variable and comparison stars are of different spectral types, this represents a reasonable night correction between the two systems when one considers (*a*) the difference in reduction procedures mentioned above and (*b*) the differences in photometer components: EMI 9502 photomultipliers (V and B channels), EMI 6256 (U channel), dichroic beam splitters, and UBV filters on the automated telescope; and RCA 1P21 and V-filter on the 16-inch telescope.

The variable amplitude of 14 Aur noted by Chevalier *et al.* is clearly seen in the light curves for January 7 and 8. The monotonic increase in amplitude on the latter date is especially striking. The light curve obtained with the 16-inch telescope on January 9 (Fig. 4) is of special interest since it has the smallest observed V-amplitude. The complete set of V data is summarized in Table 2, where we list the heliocentric times of maximum light (Δm_{MAX}) and minimum light (Δm_{MIN}) and the corresponding magnitudes, expressed in the sense "variable minus comparison."

The changes in $B - V$ and $U - B$ color indices, obtained with the automated telescope on January 7 and 8, are shown in Figures 5 and 6. An amplitude of about 0.02 mag is clearly seen in the $B - V$ values on both nights, and the variation is in phase with the V-light curve. The presence of regular variations in $U - B$ on 7 January is not obvious in the data, although there does appear to be a variation in amplitude of about 0.01 mag in $U - B$ on January 8, with minima at roughly the times of $B - V$ maxima. (For both color indices, we define "maximum" as the time of bluest light.) Note that these relations among the changes in V, $B - V$, and $U - B$ are characteristic of the δ Scuti stars (cf. Chambliss 1968) and that, at spectral type F, $U - B$ is not very sensitive to the temperature. The downward trend in $U - B$ at the end of the night, in Figures 5 and 6, may be due to differential extinction effects on the U-magnitudes of the variable and comparison stars.

The variation in amplitude of the V-light curve is associated with changes in the maximum brightness. From Figure 7, we see that an increase of 0.01 mag in the V-amplitude is associated with an equal increase in the V-brightness at maximum, with the range of both quantities being slightly above 0.06 mag. The observed range in minimum V-magnitude is only 0.02 mag. These aspects of the light variations are reminiscent of the dwarf Cepheid VZ Cnc (Fitch 1955; Danziger and Oke 1967).

The times of minimum brightness appear to occur quite accurately midway between

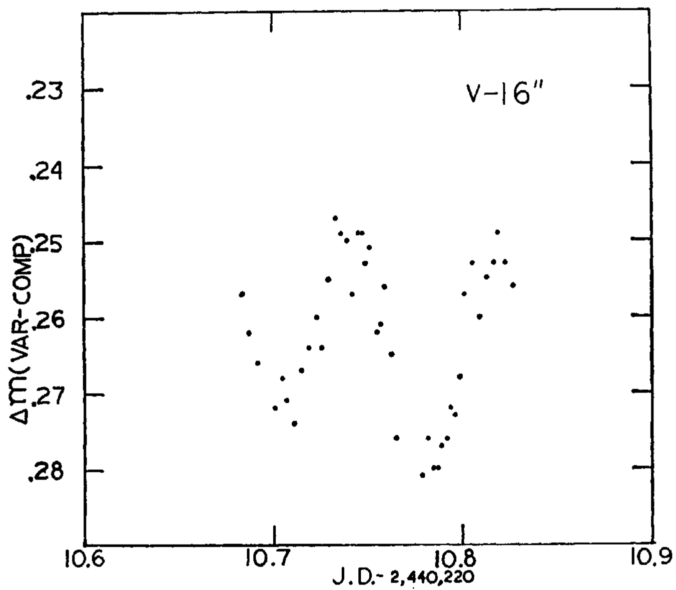


FIG. 4.—V-light curve for 1969 January 9 obtained with the 16-inch telescope. The amplitude of variation was particularly small on this night.

TABLE 2

SUMMARY OF VARIATIONS IN V-LIGHT

UT Date (1969 January)	Time of Maximum (J.D.−2440220)	Δm_{MAX} (var−comp)	Time of Minimum (J.D.−2440220)	Δm_{MIN} (var−comp)
5	6.870	0.207	6.915	0.265
7	...	...	8.685	0.270
7	8.728	0.226	...	...
7	8.820	0.225	8.864	0.269
	8.910	0.234	...	...
8	9.603	0.233	9.648	0.275
8	9.688	0.222	9.736	0.276
8	9.780	0.213	9.826	0.281
8	9.873	0.195	9.911	0.275
9	...	...	10.708	0.271
9	10.741	0.249	10.783	0.279
9	10.820	0.252	...	...
18	...	...	19.765	0.264
18	19.839	0.190	...	...
21	22.644	0.237	22.685	0.277

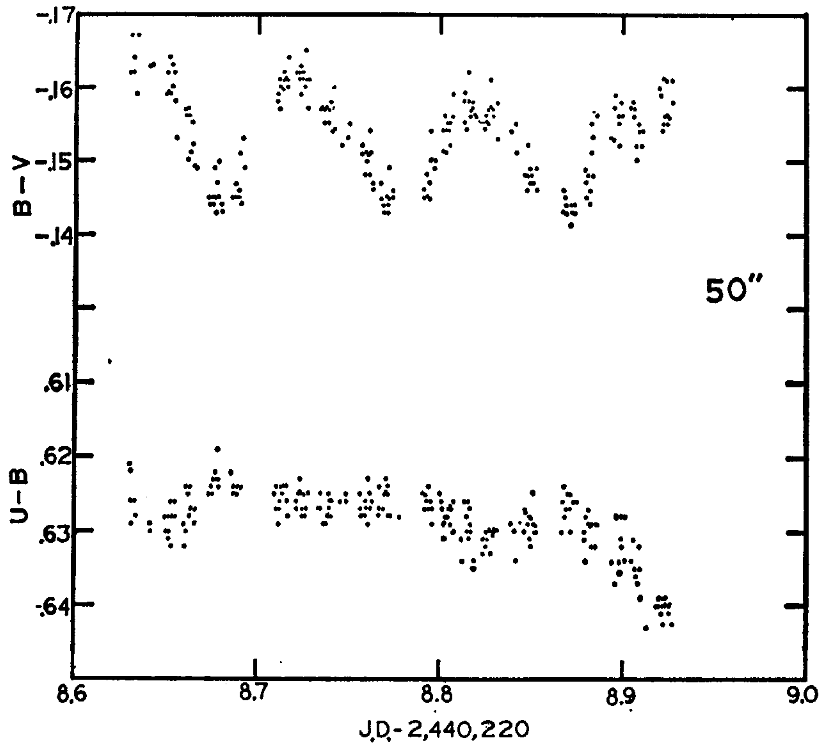


FIG. 5.—Variations in the $B - V$ and $U - B$ color indices on 1969 January 7, obtained with the automated telescope. *Abscissae*, Julian Days minus 2440220; *ordinates*, differences in color index (in magnitudes), in the sense "variable minus comparison."

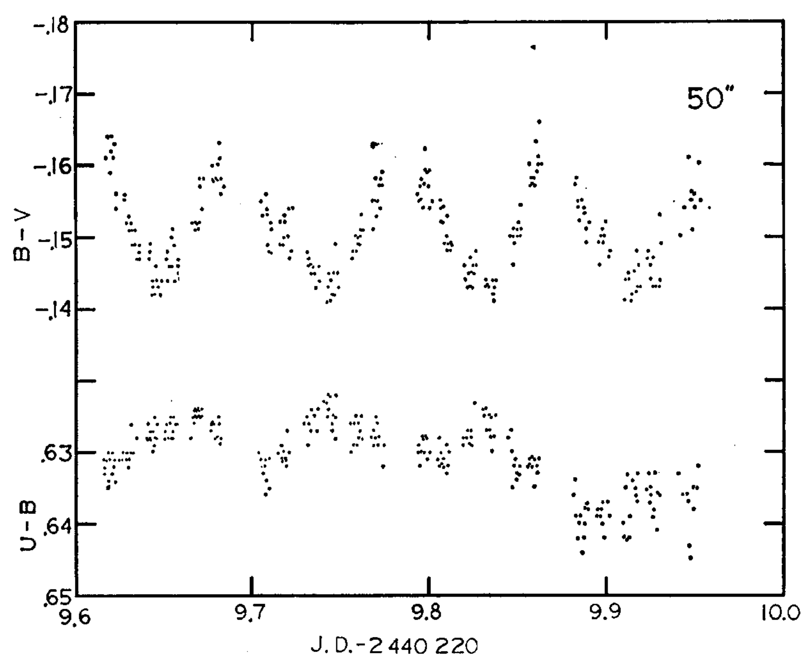


FIG. 6.—Same as Fig. 5, for 1969 January 8

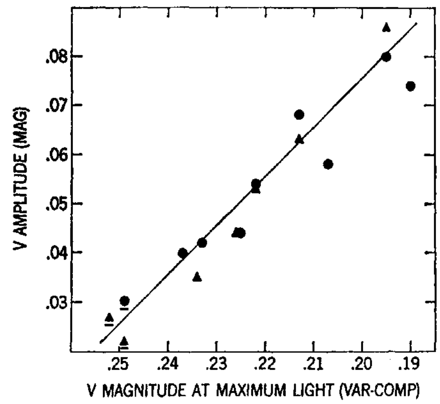


FIG. 7.—Dependence of amplitude (ordinate) of V light curve on maximum brightness (abscissa); both quantities are expressed in magnitudes. Dots are data for descending branches of the light curve; triangles correspond to ascending branches. The three underlined points represent 16-inch telescope data of 1969 January 9 for which a night correction is not available. The straight line has a slope of unity.

times of maxima. Therefore, we have used both the maxima and minima from Table 2 in a determination of the light period by the method of least squares. The period thus obtained is $P = 0^{\mathrm{d}}.08748 \pm 0^{\mathrm{d}}.00006$; a calculated epoch of maximum is J.D. = 2440226.89019. We recall that Danziger and Dickens obtained $P \simeq 0^{\mathrm{d}}.122$ for epoch 2439139 and that Chevalier *et al.* found $P \simeq 0^{\mathrm{d}}.0938$ for epoch 2439875. However, the three determinations do not necessarily reveal a secular decrease of the pulsation period. It is likely that the differences in these three values are simply due to the increased accuracy of each successive determination. On the other hand, this point can easily be settled by observations at a future epoch.

We have attempted to use the present data to test the nonradial-pulsation hypothesis for 14 Aur that was proposed by Chevalier *et al.* According to their suggestion, a plot (Fig. 8) of V-amplitude against phase in the orbital period should show two peaks,

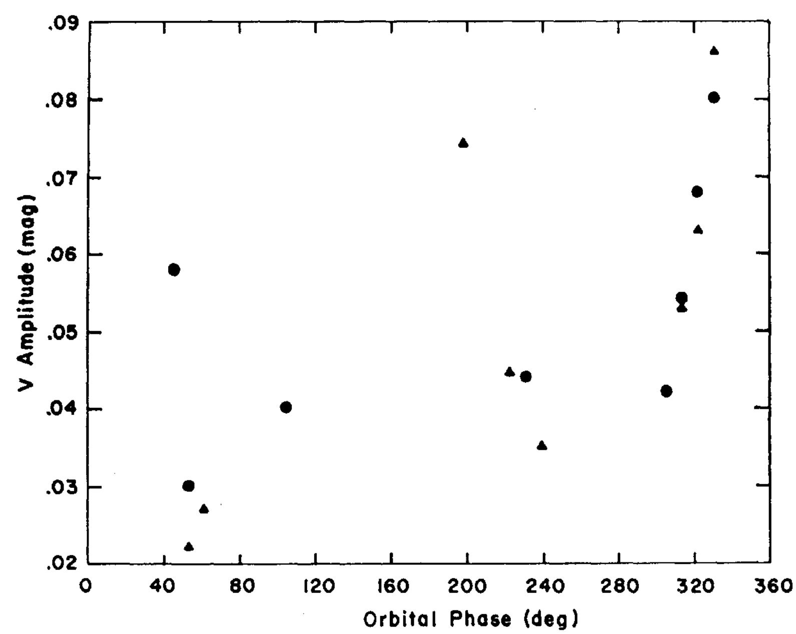


FIG. 8.—Amplitude of V light curve (ordinate) plotted against phase in the 3.788506 day binary period. Dots and triangles correspond to descending and ascending branches of the light curve, respectively.

separated by 180° in phase. In fact, there is a peak near phase 340° in Figure 8, and the data are also consistent with a peak near phase 160°, although they are inadequate to demonstrate the latter peak. In preparing Figure 8, we assigned phases based on an improved value of the orbital period, namely, $3^{d}_{\cdot}788506 \pm 0^{d}_{\cdot}000006$, derived from both the radial-velocity measurements of Chevalier *et al.* and those previously obtained by Harper. Since amplitude variations (probably due to beating between pulsations of different periods) often occur in δ Scuti stars, further observations of 14 Aur are required to determine whether the observed variations in amplitude are due to (*a*) a real dependence of the light amplitude on phase in the binary period or (*b*) beats between pulsations of different periodicities.

IV. SUMMARY

The δ Scuti star 14 Aur has been observed with an automated telescope. Comparison with results obtained by conventional means shows that the instrumental system used was well suited to the systematic monitoring of short-period, small-amplitude variable stars.

The period in V-light was $0^{d}_{\cdot}08748$. The amplitude of variation ranged from 0.02 to 0.08 mag, in association with changes in the maximum brightness. There was little change in the brightness at minimum. Changes in the $B - V$ and $U - B$ color indices with phase in the light period resemble those of other δ Scuti stars. The observations are consistant with the previous suggestion that the light amplitude has a systematic dependence on phase in the orbital period, but the data are inadequate to confirm such a relationship.

The automated-telescope experiment was made possible by the dedicated efforts of staff of the KPNO Space Engineering Laboratory, Engineering Services Department, Mountain Operations Department, and other observatory groups. We are especially grateful to Dr. J. W. Chamberlain for constant support and encouragement and to Mr. A. S. Carlson for maintaining and improving much of the hardware. We have benefitted from helpful criticism by Drs. W. S. Fitch and D. H. McNamara; we also thank Drs. M. Breger, I. J. Danziger, and K. C. Leung for their advice. One of us (H.-Y. C.) thanks Drs. N. U. Mayall and A. A. Hoag for observing time on the 16-inch telescope.

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